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The effect of seed treatments on data quality from small plots

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CHAPTER 1. GENERAL INTRODUCTION

The goal of every corn (*Zea mays* L.) is genetic progress. Genetic progress is made through selections based upon data. It is, therefore, of importance to breeders to maximize data quality. This study determines the role that seed treatments play in quality of data obtained from small plot multiple location yield trials.

Seed treatments, especially fungicides, have commonly been applied to hybrid seed corn; their role in a breeding program is not well understood though. Data are generated though a process of evaluation of genotypes. Performance of genotypes can be affected by several influences, aside from just genetic potential. Soil-borne pathogens can have a direct effect on performance. Natural resistance to soil-borne pathogens could exist for some genotypes. Inoculation of the soil-born pathogens may or may not occur. Inoculation of the seedling depends on a variety of conditions, including but not limited to: moisture, temperature, distribution of pathogens in the soil, and seed quality. (Koehler, 1957) The same could be argued for insect pests. This situation would cause variation in performance among genotypes that is due to soil-borne pathogens and/or insect pests, and not necessarily genotypic potential. Seed treatments could be the remedy to this problem.

It is not uncommon for breeders to evaluate lines from different sources. Corn breeders often use seed produced in winter nurseries, in addition to seed produced in a summer nursery or top-cross isolations. Differences among seed sources may also cause variation in performance amongst entries. Difference in seed sources may be due to differences in seed quality, which is affected by a whole slew of factors. Disease, picking, timing of picking, drying, pericarp injury, and storage conditions all affect seed quality.

(Funk et al., 1962) Difference in performance of genotypes due to seed quality may be a problem that can be corrected with seed treatments.

This experiment was set up to test the effect of seed treatment and different sources of seed on data quality. It was set up as a factorial, where five genotypes, three seed treatments, and two different sources of seed were used.

From this experiment we should be able to determine the role that seed treatments should play in a breeding program. Determining the effect they have on small plot yield trial data, especially when multiple source are used, will help us in determining the role that seed treatments should play in a breeding program

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Funk, C.R., J.C. Anderson, M.W. Johnson, R.W. Atkinson. 1962. Effect of Seed Source and Seed Age on Field and Laboratory Performance of Field Corn. Crop Science 2:318-320.

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CHAPTER 2. LITERATURE REVIEW

Introduction

The objective of this research is to identify the role that seed treatments should play in a breeding program. The more specific question being asked is what role do seed treatments play in the quality of data collected from small plot yield trials. The hardest part of breeding is correctly identifying the best performers to recombine or advance for line development. If seed treatments can take out or reduce environmental effects on small plot yield trials, then seed treatment should increase the quality of a breeder's data.

A study on the role of seed treatments in a breeding program and the effect of seed treatments on data quality has not been conducted, to the author's knowledge. No published research that specifically addresses this issue could be found. The problem of identifying the effects of seed treatments on small plot yield trials is much more complex than one might imagine. Any possible answer could involve the interactions of seed quality and the seed treatments. I could not find any literature on the subject of the use of seed treatments in a breeding program, but literature pertaining to issues important to breeders was found. This literature review will be very broad in scope. It will review the origins and beginning of seed treatments. It will also cover the evolution of seed treatments as a use on small grains to their use on corn. Several studies were conducted on the early seed treatments of corn. Their findings will also be a topic of this chapter. Other topics being discussed will range from seed quality to seedling vigor. The effects of seed treatments on seedling phenotypic characteristics and grain yield will also be a topic. Based upon these published findings, we may be able to put together some explanations and reasons for what we observed in our own experiment.

The beginnings of seed treatments.

The use of seed treatments on corn are as old as the species itself. Many of the American indian tribes had their own seed treatments; however, most of these treatments were based upon their religious beliefs, and the scientific merit of these treatments have not been studied. Many indian tribes such as the Sioux, Gras, Ventre, Arikara, and Chippewa germinated their seed corn prior to planting it. This ensured a good stand and quick emergence (Biggar, 1918). Modern seed treatments have their beginnings in small grains, where treatments were used to control head smut. Copper sulfate was used for control of smut in wheat in the mid 1800's. Formaldehyde was also used for smut control in small grains starting in 1896. Also developing at this time were a variety of mercury based compounds that were used as treatments. Most all of the first seed treatments were used primarily for the control of smut on small grains (Moore, 1953). Starting around the beginning of the 20th century these seed treatments found a new use in corn. Formaldehyde as a seed treatment for corn was first published in a study by Richey, (1920) testing its effects on germination and vigor. Private industry soon began the development and marketing of seed treatments for corn. Many of these seed treatments were mercurials. These seed treatments were the subject of studies in the 20's and 30's. These publications used seed treatments available at the time (Melchers & Brimson, 1934; McClelland & Young, 1934) such as Improved Semesan Jr., Bayer Duster, Uspdum, Kolodust, and others. While these mercurial organics were eventually discontinued as seed treatments, they were the predecessors of today's seed treatments, as many of today's modern seed treatments are produced by companies who had their beginnings in these older seed treatments.

Addressing the Issue of Seed Treatment on Stand, Vigor, and Yield

Seed treatments, especially those that guard against soil borne pathogens, have been the subject of academic studies. Seed treatments have largely been developed in the private sector. Because of this, much of the research that has been published is older, but not necessarily outdated, as there are still lessons to be learned from this research. These lessons can be taken into consideration when conducting an experiment involving seed treatments. Most seed treatment studies look for differences in stands, vigor, and ultimately yield. As previously mentioned, formaldehyde was one of the first seed treatments used on corn. Formaldehyde has adverse effects on germination, and Richey (1920) conducted a study on several different concentrations of formaldehyde, studying the effects on germination and the rapidity of germination and growth (vigor). It was found that a concentration of 5 cc litre^{-1} controlled fungus development and did not affect germination rates or seedling development when seeds were soaked in the solution for 30 minutes and then removed. The old seed treatments that soon followed formaldehyde included Improved Semesan Jr., Bayer Duster, Uspdum, Kolodust (sulfur), copper carbonate, Creolin, Merko, Sterocide, Borlak, and Sturdidust. These old seed treatments, many of them organic mercurials, were tested in two studies published in the same year (Melchers & Brimson, 1934; McClelland & Young, 1934). Using these seed treatments neither of the papers could conclude that treating seed was worth the cost. None of the treatments consistently increased stands. Melchers & Brimson (1934) used 20 different samples of seed corn collected from farmers' seed corn supplies. The twenty different farmers were from 20 different counties in the corn producing regions of Kansas. In these days farmers were growing open pollinated populations of corn and were keeping back their own seed, so one would expect some variabiabilty in the varieties corn and some variation in the quality of seed. Melchers and Brimson (1934) only observed better stands with some treatments in 1929; however, this did not result in higher yields. McClelland and Young (1934) used only one corn variety, Neal's Paymaster. In this paper the authors tried to determine under what conditions would the treatment of seed most likely be profitable to the farmers of Arkansas. McClelland and Young (1934) had a planting date component to their experiment over the four years that it was conducted. Differences in seed treatments and untreated checks for stands varied sporadically between planting date and year. When considering yield, some seed treatments gave increases in yield some years, at some planting dates. In short the authors could not correlate a seed treatment response with plating date or weather patterns of the planting dates.

Publications on modern fungicide seed treatments have proved harder to come by. Some studies have been published regarding the effects of systemic insecticides. Seed treatments having a "stimulation" effect on the seedlings was noted by M.B. More (1953). He claims that this is probably due to control of seed-borne and soil-borne pathogens. This "stimulation" effect brought about by systemic insecticide seed treatments even in the absence of pests have been suspected, and eventually the topic of published research. Pless et. al (1971) found that the systemic insecticide carbofuran and disulfotar significantly increased yields of burley tobacco 160-180 lbs/acre respectively. It was also found that carbofuran had similar effects on corn, significantly increasing yields 1.9 to 6.9 % when applied in the seed furrow (Apple, 1971). These two studies however, fail to make note of the presence or absence of seedling insect pests. Wilde and Roozeboom (1999) studied the effect of the systemic insecticide seed treatment Gaucho (imidacloprid) on grain sorghum [*sorghum bicolor* (L.) Moench] yield. They found that in the absence of insect pests that Gaucho did not increase yields in grain sorghum. During the two year period of this study, over five locations, seventy Gaucho versus untreated hybrid comparisons were made where no insect pest infestations were observed. Significant yield differences were detected in only one yield comparison where an untreated hybrid out yielded its Gaucho counterpart. Significant differences were observed only twice where the Gaucho treated hybrid out yielded the untreated hybrid.

Addressing the issue of seed quality on stand, vigor, and yield

Any differences observed between seed sources could be due to differences in seed quality. Therefore, the effects of seed quality on measured traits such as yield are also of interest. Seed quality can be linked to a multitude of factors, some of them are identifiable and others are not. Funk et al. (1962) cites the following possibilities as reasons for low seed quality: immaturity, frost damage, drying at high temperatures, herbicide injury, pericarp injury, phytotoxic seed treatments, seed-borne fungi, and improper storage conditions. All of which have been proven to lower germination and vigor of seed corn. Funk et al. (1962) summarizes Delouche and Caldwell's (1960) opinion that "the literature contains very little data...none of which is very conclusive...showing that vigor differences...affect yield." Funk et al. (1962) observed differences in yield of the same hybrid that originated from different sources. These different sources of seed were classified by their differences in seed quality. Weaker seed lots were detected by seed quality tests, which was obtained by means of a cold germination test. These seed lots emerged slower, exhibited less vigor, were lower eared, and were lower yielding, even when thinned to identical stands. Kaerwer (1953) reported that picking seed corn at high moistures, especially those moistures higher than 32-35% reduced field stands and also reduced the hybrids ability to perform in a cold germination test. Kaerwer (1953) also found that the same was true for different sources of mechanical damage. Grawen and Carter (1991) looked for a seed quality x tillage system interaction. Their seed qualities were classified into low (84-86% germination) medium (87-95% germination) and high (>95% germination). All seed was treated with Captan fungicide seed treatment. They studied three different types of tillage systems in the state of Wisconsin. Conventional tillage, no-tillage, and no-tillage with the residue removed over a six inch strip over the seed row were the three types of tillage. Their objective was to determine if farmers conducting no-till operations needed higher quality seed to counter any adverse conditions (mostly cooler soil temperatures) associated with no-till in the Northern corn region of Wisconsin. They found that tillage system x seed quality interactions were unimportant for growth and yield. There was however, a relationship between medium and low quality seed and delayed seasonal growth and reduced grain yields. They did not find a significant seed quality x hybrid interaction for grain yield, except for one year at one location a significant interaction was observed.

Again, by introducing the seed source effect into our study we may be in fact introducing differences in seed quality effect. Seed quality can have an effect on germination, stand, and vigor, of which, any or all may or may not have an effect on yield. Vigor, which generally is effected by anything affecting the seed during development and maturation, is hard to measure, and not easily defined. Vigor has been showed though to have an effect on yield, in some hybrids, yet in other hybrids, it proved to not have any effect (Burris, 1975). This difference in yield was observed on plots that were over-planted, and thinned back to constant stands, across different vigor levels. Burris (1975) found differences in yield across the three different ratings of vigor. Vigor was measured by taking a dried seedling weight. The seed lots were placed in a rolled towel germination test for 7 days. The roots and shoots were removed from the seeds, dried, and weighed.

Most processes involved in preparing seed for spring planting affect the quality of the seed. Seed quality, as previously discussed, can have an effect on stand, vigor, and yield. Picking, drying, shelling, and the moisture at which all of the previous were conducted can cause damage to the pericarp. There are several types of pericarp injury that affect the quality of the seed. Koehler (1957) studied these different types of pericarp injuries and the effects that seed treatments had when these different injuries were present. Four types of pericarp injuries were studied; plumule exposed, crown injured, radicle exposed, and no injury at all (sound pericarp check). Injured seed was either treated with 1 ounce of Arasan per bushel (29.58 cc per 27.22 kg of seed) or no seed treatment was applied. Arasan is a fungicide seed treatment. Both stand counts and yield data were collected in this field experiment. The sound check seed produced no differences between the treated and untreated seed in both stand count and yield. Injured seed did produce differences. Crown injured and radicle exposed seed, when treated, did not produce different stands or yields than that of the treated sound check seed. Plumule exposed seed produced differences between the treated and untreated seed, however, seed treatment was not enough to compensate for this damage and bring it within the LSD of the sound check seed. A cold test was also conducted on crown injured seed. The variables in this test were; days at 50° F

(10°C), level of seed treatment and seed injury. Measurements were taken on stand and on green weight. Green weight could be viewed as a measure of vigor. The levels of seed treatment used were; no seed treatment, ½ ounce per bushel (14.78 cc per 27.22 kg of seed), and 2 ounces per bushel (59.15 cc per 27.22 kg of seed). Seed lots were placed at 50° F for 0, 5, 10, or 20 days. Seed treatment had a major effect on stands, both in the sound seed and in the injured crown seed. Sound seed treated with 2 ounces of Arasan per bushel could still achieve 91 % stand after 20 days of cold treatment. Furthermore, crown injured seed, when treated with ½ oz of Arasan, after 5 days of cold treatment was able to achieve 99 % stand, and when treated with 2 oz of seed treatment, after 10 days of cold treatment 98 % stand could still be achieved. While the seed treatment seemed to compensate for this type of pericarp injury when it came to stands, it had a harder time compensating for differences in vigor, or the green weight. Injured seed still produced significantly less green weight than the sound seed. Treated seed still performed better than the untreated seed, but the seed treatment did not fully negate the effects of the pericarp injury.

It is important to note that there are several components of seed quality, including: analytical purity, species purity, freedom from weeds, cultivar purity, germination capacity, seed vigor, seed size, uniformity, health (seed-borne diseases), and moisture content (Thomson, 1979). What has commonly been referred to as seed quality can probably be more accurately referred to as one of the components of seed quality. In the case of our study, our measurement of seed quality is really a measure of seed vigor. Seed vigor is defined by the Association of Official seed Analysis as "those seed properties which determines the potential for rapid, uniform emergence and development of normal seedlings under a wide range of field conditions" (Copeland and McDonald).

Based upon the literature discussed, there is some evidence that seed treatments affect performance of corn. There is also evidence that some components of seed quality also have an affect on performance of corn. Furthermore, Koehler (1957) determined that there is a response to seed treatments when seed quality is compromised. Compiling all that is learned from these studies, it would suggest that seed treatment does indeed affect the quality of data. Lower seed quality reduces the plants ability to handle environmental stresses, especially soil-borne pathogens. Lower seed quality results in lower performance, and thus a less accurate representation of a corn line's ability to yield. If seed treatment can reduce these differences associated with seed quality, selecting the highest performers will be easier for the breeder, and more progress could potentially be made in a cycle of selection.

In this research project I will be using three seed treatments: Maxim XL, Maxim XL and Cruiser, and no seed treatment. Maxim XL is a Syngenta product. It is a combination of Maxim and Apron XL. The two active ingredients are fludioxonil and mefenoxam. Fludioxonil belongs to the chemical class phenypyrrodes, which interferes with transport mechanisms in fungal cells, interacting with various points in the life cycle of the fungus. Maxim XL is used primarily to control pythium and fusarium in corn (Munkvold, 1998). Cruiser is a Syngenta product as well. Cruiser is designed to provide early season broad spectrum, pest control. Cruiser is a neonicotinoid, more specifically its active ingredient is thiamthoxam. It is a systemic insecticide seed treatment that is licensed to be used on corn, cotton, cereals, sugar beet, canola, and rice. According to the label, Cruiser protects germinating seeds from damage and stand loss from wireworms and seed corn maggots (Syngenta). It also provides protection against white grub, flea beetles, chinch bug, and suppression of black cutworm at the seedling stage (McLeod, 2003).

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CHAPTER 3. THE EFFECT OF SEED TREATMENTS ON DATA QUALTITY FROM SMALL PLOTS

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Abstract

Corn (*Zea Mays* L.) breeders make selections based upon data. Any means of improving data quality would be desirable. This study was conducted to determine the effects of seed treatments on data obtained from small plot multiple location yield trials. The factorial experiment consisted of 3 seed treatments, and 5 hybrids, from 2 seed sources grown in a Randomized Complete Block Design (RCBD) at 4 locations with 3 replications per location. The 3 seed treatments used were: no seed treatment, Maxim XL, and Maxim XL + Cruiser. Seed was produced in the 2003 summer nursery and the 2003-04 winter nursery in Chile. The two seed sources differed in seed quality. The Maxim XL treatment improved stand, vigor, and yield in winter seed, where seed quality was lower. Cruiser did not provide any additional benefit, except for a slight increase in stand, which did not result in an increase in yield. Treating seed, especially with a fungicide seed treatment such as Maxim XL, improves data quality obtained from small plot multiple-location yield trials by minimizing differences in performance that are associated with different qualities of seed.

Introduction

The goal of any breeder is to select the best performing entries for either recombination or for line development. The probability of selecting the best performers is maximized when data quality is maximized. Data quality is affected by many different management practices in a breeding program. Breeders must then determine the best way to manage their program to produce the highest data quality. A corn breeder selects on several different traits, the most important of which is yield. The general formula $\sigma_p^2 = \sigma_g^2 + \sigma_e^2$ is one that all breeders recognize and understand. The phenotypic variance (σ_p^2) is equal to the sum of the genotypic variance (σ_g^2) and the environmental variance (σ_e^2). The breeder does the best that he can to select based upon σ_g^2, but unfortunately, σ_e^2 causes hidden problems. Therefore, the goal of breeders is to minimize the contribution of σ_e^2 to σ_p^2. The use of seed treatments could potentially reduce σ_e^2, thus allowing for a better representation of the genotype by direct measure of the phenotype.

A corn breeder has several tools available to increase genetic gain, including the utilization of winter nurseries. Using seed produced in different production environments will likely have a negative effect on data quality, due to the potential for differences in seed quality. (Bdliya & Burris, 1988; Burris, 1977). Of larger importance and interest is the interaction that may exist between seed treatments and seed sources. Can seed treatments minimize or eliminate the negative impact of seed source on data quality?

Modern seed treatments effectively guard against targeted pests (McLeod & Butzen, 2003; Munkvold, 1998). What may not be so clear is the role of seed treatments in a breeding program. Some breeders feel that the use of seed treatments prevents them from selecting for resistance to soil-borne pathogens, eliminating a trait from selection, but there is no published data to support this view. For selection to be effective for resistances to soil-borne pathogens, the pathogens would need to be evenly distributed in the soil profile around planting depth, the distribution of species would need to be consistent, and there would need to be genetic variation in corn for resistance. Natural variation among inbred lines, and consequently hybrids, may or may not exist in corn for resistance to soil-borne pathogens that are controlled by seed treatments. Furthermore, because the distribution of soil-borne pathogens in the soil is unknown, escapes may be a frequent problem. Therefore, variation in performance among entries in yield trials could be based upon either resistance of the entry to soil born pathogens or a lack of inoculation by the pathogens.

The role of seed treatments in breeding programs has not been the subject of any literature that is known to the authors. Several papers on the use of seed treatments have been published though. Melchers & Brunson (1934) along with McClelland and Young (1934) tested several seed treatments. Both papers concluded that seed treatments did not provide an increase in yield, and thus were not worth the investment. Wilde et al. (1999) studied the effects of the seed treatment Gaucho (Gustafson; Plano, Texas) on yield of grain sorghum. They found that Gaucho did not increase yields of grain sorghum when no pest infestations were observed, thus the study dealt strictly with the effect of Gaucho on the sorghum crop and had nothing to do with the effectiveness of Gaucho as a seed treatment. Gaucho is a systemic insecticide seed treatment.

Differences in performance among identical cultivars produced from different seed sources could be due to differences in seed quality. Therefore, effects of seed quality on measured traits such as yield are also of interest. Funk et al. (1962) cites the following possibilities as reasons for low seed quality: immaturity, frost damage, drying at high temperatures, herbicide injury, pericarp injury, phytotoxic seed treatments, seed-borne fungi, and improper storage conditions, all of which have proven to lower germination and vigor of seed corn. Grawen and Carter (1991) noticed medium and low quality seed had delayed seasonal growth and reduced grain yields when compared to high quality seed. Poor seed quality may also reduce seedling vigor. Burris (1975) showed that vigor has an effect on yield in some hybrids but not others. Significant differences were found in yield across three different ratings of vigor. Koehler (1957) studied the effects that seed treatment had on different types of pericarp injuries. The seed treatment used was Arasan, a fungicide seed treatment, applied at the rate of 1 ounce per bushel (29.58 cc per 27.22 kg of seed). Treatment of Arasan did not improve the stands or yield of non-injured seed; however, treatment with Arasan did improve the stand and yield of injured seed. Koehler (1957) also found that seed treatment improved stand and vigor when injured seed was exposed to extended periods of cold temperatures [50° F (10°C) for 0, 5, 10, and 20 days]. Koehler (1957) measured green weight of seedlings, (a measure of vigor) produced from pericarp injured seed and found that treated seed always performed better than untreated seed, but the seed treatment did not fully negate the effects of the pericarp injury.

Based upon the literature discussed, there is some evidence that seed treatments affect performance of corn. There is also evidence that seed quality has an effect on performance of corn. Furthermore, Koehler (1957) determined that there is a response to seed treatments when seed quality is compromised. There are several components of seed quality, including: analytical purity, species purity, freedom from weeds, cultivar purity, germination capacity, seed vigor, seed size, uniformity, health (seed-borne diseases), and moisture content

(Thomson, 1979). What has commonly been referred to as seed quality can probably be more accurately referred to as one of the components of seed quality. In the case of this study, our measurement of seed quality is really a measure of seed vigor. Seed vigor is defined by the Association of Official seed Analysis as "those seed properties which determines the potential for rapid, uniform emergence and development of normal seedlings under a wide range of field conditions" (Copeland and McDonald). Seed treatments could correct for the effects of low seed vigor, which could improve data quality. Low seed vigor reduces the plants ability to handle environmental stresses. Lower seed vigor can result in lower performance, and thus a less accurate representation of a corn line's ability to yield. If seed treatment can reduce these differences associated with seed vigor, selecting the highest performers will be easier for the breeder, and more progress could potentially be made in a cycle of selection.

Our objective was to determine if the treatment of seed for small plot evaluation in multiple location yield trials is worth the investment in time, equipment, and money that is required to treat the seed. Another objective of this study is to test the effect of seed source on data quality as well. The research presented herein studies the effects of seed treatments and seed sources on the quality of data obtained from small plot yield trials.

Materials and Methods

For this study a factorial design was used. The components of the factorial are: five hybrids, two seed sources, and three seed treatments for a total of 30 treatment combinations. The hybrids that were used were produced from five different inbred lines of both public (Iowa State University; Ames, Iowa) and private (Holden's Foundation Seeds; Williamsburg, Iowa) sources. The hybrids that were used are B110/B122, B110/LH295, LH244/B125, LH244/LH295, and LH244/B122. These five hybrids were produced in Boone County, Iowa in the summer of 2003 and were produced again during the 2003-2004 winter in Chile by CRD Inc. (Ames, Iowa). All seed was produced by hand pollinations using the inbred on the left of the pedigree as the female. The only exception to this was the hybrid B110/LH295 from the summer seed source. It was produced in top-cross isolation with B110 as the female. All five hybrids from both seed production environments were treated with three different seed treatments. The treatments were: no seed treatment applied, Maxim XL, and Maxim XL + Cruiser. Maxim XL (Syngenta Crop Protection Inc. Greensboro, North Carolina), a fungicide seed treatment, was applied at a rate of 0.25 fluid ounces per 100 lbs of seed (7.39 ml / 45.40 kg). Cruiser 5FS (Syngenta), a systemic insecticide seed treatment, was applied at a rate of 0.125 mg active ingredient per kernel. All seed treatment was applied to the seed in liquid form using a plot seed treatment applicator.

Entries were planted in two row plots. Rows were on 76.2 cm centers and were 5.18 m long. Thirty-two kernels per row were planted for a total of 64 kernels per plot. Stand counts were taken, as will be later explained, but plots were not thinned to a uniform number. All fields in this experiment had soybeans as the previous crop. The experimental design for this study was a randomized complete block design (RCBD). The experiment was grown at four locations with three replications at each location. The four locations were Ames, Calumet, Kanawha, and Nashua. Calumet was not harvested due to widespread damage to the location caused by a late summer storm. Soil temperatures at Calumet, Nashua, and Kanawha at time of planting were 10-13°C. Ames had a soil temperature of 17°C at time of planting.

Data were collected on several traits in the experiment. A stand count and a seedling vigor rating were taken at emergence (VE-V1). Seedling vigor was rated on a scale of 1 to 3, with a 3 being the most vigorous. In order to score a rating of 3, the plot must have had a good stand with uniform seedling size across the plot. A second stand count was taken upon full establishment (V3-V5). Other traits that were measured were root lodging (%), stalk lodging (%), grain moisture at harvest (g kg^{-1}), and grain yield (Mg ha^{-1}) adjusted to 155 g kg^{-1} grain moisture. Grain yield and grain moisture were measured by machine harvesting with a plot combine. Root lodging was the percentage of plants leaning greater than 30 degrees from vertical. Stalk lodging was the percentage of plants broken at or below the primary ear node. Germination tests were conducted by the ISU Seed Testing Laboratory on hybrids where at least 200 seeds were available after planting. Only 3 hybrids were tested from both summer and winter seed sources: B110/B122, LH244/B122, and LH244/LH295. An official test requires 400 seeds, and only 200 seeds were provided.

Data were analyzed by partitioning out the sources of variation of interest and conducting an analysis of variance with the appropriate F-tests. The sources of variation of interest were the three main effects, the two-way interactions among the main effects and the one three-way interaction. A standard outlier analysis was conducted on grain moisture and grain yield by using the Anscombe and Tukey method (1963). In the model, locations were considered a random effect, replications were nested within location and was considered a random effect. Hybrid, seed source, and seed treatment were all considered as fixed effects. Comparisons of means were made using an LSD. LSD's were calculated using the location x entry mean square error (MSE).

For the traits of early stand count, seedling vigor, and late stand count, the experiment was analyzed over four locations. Percent root lodging, percent stalk lodging, grain yield, and grain moisture, the experiment was analyzed over three locations, as one location was not harvested. In addition to testing for significance of main effects, the interactions were also tested for significance.

Results and Discussion

Hybrid, differed for all traits measured (Table 1). Hybrid performance for yield ranged from the low hybrid, B110/B122, with a yield of 11.71 Mg ha^{-1} to the top yielding hybrid, LH244/B125, with a yield of 12.95 Mg ha^{-1} (Table 2). The variation among hybrids for yield stemmed largely from the winter seed source and if winter seed were removed from the analysis, hybrids did not differ for yield.

Seed treatment, produced significant results for several of the traits measured (Table 1). Seed treatments having an effect on stand counts and vigor seems consistent with the literature previously discussed (Koehler, 1957). The most significant finding was that seed treatment can in fact have a significant effect on yield. Averaged across all sources and hybrids, seed treated with Maxim XL yielded 0.76 Mg ha^{-1} more than untreated seed. Cruiser did not provide any additional yield advantage over seed treated with just Maxim XL (Table 2).

Maxim XL, when measured across all traits for which seed treatment was significant, produced more desirable results than untreated seed (Table 2). Maxim XL treated seed provided an increase in seedling vigor of 0.24 and an increase in early and late stands of about 4 plants per plot for each trait. There were never any differences between

Maxim XL and Maxim XL + Cruiser except for a slight increase in late stand count associated with the use of Cruiser (Table 2). This may be due to the fact that plots were always planted on ground where soybeans had been the previous crop. This would mean that fewer insect pests were present, had those insects been present, more differences with Cruiser may have been observed. The seed treated with Maxim XL showed its biggest advantage in the winter produced seed where seed vigor was almost always poorer than summer produced seed (Figure 1). When the winter nursery seed was removed from the analysis of variance, leaving just the summer seed, there were no differences among the measured traits, except for late stand count.

Seed source was different for several traits of interest (Table 1). In addition to being different for stand counts, seedling vigor, and yield, it was also different for moisture and root lodging. Several observations would seem to suggest that our differences in seed source are actually differences in seed vigor. Lower stand counts were recorded for winter seed and an unofficial germ test conducted by the ISU seed lab found especially poor germination in B110/B122 winter source along with abnormal root development. The reason for differences between the two sources for moisture can again be explained by differences in seed vigor among sources. Grawen and Carter (1991) observed delayed seasonal growth in lower quality seed lots. A delay in seasonal growth could result in elevated levels of grain moisture, which was observed in the winter hybrids B110/B122 and B110/LH295. Source did have an effect on yield, as summer seed significantly out yielded winter seed.

The hybrid x seed treatment interaction was only significant for the two stand counts (Table 1). This is due to the B110/B122 winter hybrid, which saw the largest benefit of Maxim XL seed treatment, as stands increased by 25-27% for this hybrid (Table 3). When

B110/B122 was removed from the analysis, no hybrid x seed treatment interaction was seen for the two traits.

The hybrid x seed source interaction was significant for all traits except for moisture (Table 1). A significant hybrid x seed source interaction could be thought of as a maternal inbred x environment interaction, where that interaction has a direct effect on seed vigor and germination potential, and consequently measured traits of the resulting hybrid. Hybrid x seed source interactions should be expected because maternal inbreds react differently to varying environmental conditions, thus affecting some components of seed quality differently across hybrids. Many of the environmental conditions (e.g. disease, drought, insects, and harvesting and shelling methods) that influence seed vigor can be controlled to some extent. This was obviously the case of the B110/B122 winter source seed. The seed appeared to have been harvested at too high of moisture or perhaps before all the kernels reached physiological maturity. Most of the hybrid x seed source effect was due to the B110/B122 hybrid. When this hybrid was taken out of the analysis, the hybrid x seed source interaction for yield and stalk lodging was not significant. The effect of seed source on yield was greatest for the B110/B122 hybrid, while seed source did not affect yield in LH244/LH295 (Table 4). The seed vigor and germination capacity issues were probably not observed in the B110/LH295 hybrid to the extent that it was in B110/B122 because B110 nicks better with LH295. B122 was probably used to pollinate a delayed row of B110 in Chile, there by delaying development when compared to the B110 pollinated by LH295.

The seed source x seed treatment interaction was significant for all measured traits except for moisture and stalk lodging. A seed treatment x seed source interaction suggests that different treatments have varying effects on the differences in seed vigor, brought about by using seed from multiple sources. There were suspected differences in seed vigor due to production environments. This seemed to have varying effects on hybrids; however, treating the seed with Maxim XL reduced these effects (Figure 1). Untreated winter seed yielded less than the treated winter seed (Table 5). Treating seed with a fungicide such as Maxim XL has the possibility to compensate for some of the shortcomings associated with lower seed vigor. The hybrid with the lowest seed vigor was B110/B122 from the winter source. While treating the seed with Maxim XL did not entirely eliminate differences in yield due to seed source, it did certainly reduce those differences. When treated with Maxim XL + Cruiser, the winter and summer seed sources were within the LSD for yield (Table 5). If the differences in seed vigor are small, then treating seed with Maxim XL could come close to negating the differences associated with different levels of seed vigor.

Conclusions

The conclusions reached by the authors are important to corn breeders. First, differences in the quality of seed produced from multiple sources were observed. These differences in quality probably stemmed from lowered seed vigor and a reduction in germination capacity as evidence by reduced early stand, seedling vigor rating, and germination test results. Thus, seed quality had a profound impact on traits that breeders measure and select on, including stand counts, vigor, lodging, and yield. If it is at all possible, a breeder should try to use seed that originates from a single source in an experiment, and emphasis on producing high quality seed should be made when producing the seed. If the breeder determines he must produce seed in winter nursery, then care should be taken whenever possible to ensure the highest standards of quality when producing that seed. Such effectors of seed quality as premature harvesting, improper drying, and poor handling and storage techniques should be avoided.

Treatment of seed is of particular importance to breeders. If the seed is of superior vigor, treating seed may not be necessary; however, making a decision not to treat seed though may not be a risk worth taking. Based upon this study, it may not be necessary to treat with a systemic insecticide, but it certainly appears that treating with a fungicide seed treatment is worth the investment. It would suggest that treating with a fungicide seed treatment helps to ensure quality data by reducing differences in performance that stem from differences in seed vigor. This ensures that differences in performance are more likely due to differences in genotype. Moore (1953) wrote "Lastly, seed treatment is not a substitute for good seed. True, it permits the use of seed less than top vigor, but as the various degrading factors add up we eventually come to a point where even treated seed will fail in cold wet soil." We agree with Mr. Moore's conclusions; high quality seed has to be the first priority.

It is the conclusion of the authors that treating seed for multi-locational yield trial plot experiments is worth the investment in time and money that is required of it. Furthermore, treating seed becomes an even larger necessity if the seed originates from multiple sources or if seed vigor may have been compromised. The use of seed treatments improved data quality.

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Table 1 - Results from the Analysis of Variance of measured traits.

Source of Variation	Early Stand	Vigor	Late Stand	Root Lodging	Stalk Lodging	Moisture	Yield
Hybrid	***	***	***	***	***	***	***
Treatment	***	**	***	NS	NS	NS	**
Source	***	***	***	*	NS	*	***
Hybrid x Treatment	***	NS†	***	NS	NS	NS	NS
Hybrid x Source	***	***	***	**	*	NS	***
Treatment x Source	***	*	***	NS	NS	NS	**
Hybrid x Treatment x Source	***	NS	***	NS	NS	NS	NS

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.
† NS, nonsignificant at the 0.05 level.

Table 2 - Means reported for seed treatments, seed sources, and hybrids.

Experimental Variable	Yield	Vigor	Stand		Moisture	Lodging	
			Early	Late		Stalk	Root
	Mg ha^{-1}†	‡	§		g kg^{-1}	%	
Treatment							
Untreated	11.75	1.88	51.65	50.71	21.1	0.026	0.026
Maxim XL	12.51	2.12	55.38	54.70	20.8	0.031	0.024
Cruiser	12.58	2.13	56.39	57.12	21.1	0.033	0.021
Untreated vs Maxim XL	**	**	***	***	NS ¶	NS ¶	NS ¶
Maxim XL vs Maxim XL + Cruiser	NS ¶	NS ¶	NS ¶	***	NS ¶	NS ¶	NS ¶
Source							
Summer	12.88	2.42	58.04	56.98	20.8	0.032	0.028
Winter	11.69	1.66	50.91	51.36	21.2	0.028	0.019
Summer vs Winter	***	***	***	***	**	NS ¶	NS ¶
Hybrid							
B110/B122	11.71	1.68	48.36	49.53	223.7	0.051	0.025
B110/LH295	12.14	1.89	51.09	52.02	200.8	0.017	0.062
LH244/B122	11.89	1.97	58.13	56.69	217.9	0.021	0.005
LH244/B125	12.95	2.26	58.57	57.58	209.1	0.045	0.003
LH244/LH295	12.72	2.40	56.22	55.06	198.2	0.015	0.023
LSD (0.05)	0.56	0.17	1.60	1.49	4.8	0.012	0.014

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† Adjusted to 155 g/kg moisture.

‡ Measured on a scale of 1 to 3, 3 being most vigorous.

§ Stand counts were taken early, VE-V1, and late, V3-V5. Reported as number of plants out of 64 kernels planted.

Table 3 - Means reported for hybrid x seed treatment interaction.

Hybrid	Treatment	Yield	Vigor	Stand Count		Moisture	Lodging	
				Early	Late		Stalk	Root
		Mg ha^{-1}†	‡	§		g kg^{-1}	%	
B110/B122	Untreated	11.02	1.54	40.79	42.04	226.5	0.037	0.036
	Maxim XL	12.24	1.79	51.58	52.04	220.4	0.054	0.027
	Cruiser	11.88	1.71	52.71	54.50	224.2	0.061	0.013
B110/LH295	Untreated	11.92	1.94	50.84	49.53	197.8	0.021	0.067
	Maxim XL	11.78	2.22	50.26	50.10	201.5	0.016	0.068
	Cruiser	12.72	2.22	52.18	56.43	203.0	0.016	0.052
LH244/B122	Untreated	11.05	1.79	55.83	54.33	221.4	0.018	0.008
	Maxim XL	12.07	2.04	58.33	57.63	215.9	0.023	0.006
	Cruiser	12.54	2.08	60.21	58.13	216.4	0.023	0.000
LH244/B125	Untreated	12.48	2.17	56.67	55.58	209.3	0.036	0.002
	Maxim XL	13.65	2.30	59.80	57.87	204.4	0.050	0.007
	Cruiser	12.72	2.33	59.25	59.29	213.6	0.050	0.000
LH244/LH295	Untreated	12.30	2.21	54.13	52.04	199.1	0.015	0.016
	Maxim XL	12.83	2.54	56.92	55.88	198.9	0.012	0.013
	Cruiser	13.02	2.45	57.63	57.25	196.6	0.017	0.040
LSD(0.05)		0.96	0.29	2.76	2.58	NS ¶	NS ¶	NS ¶

† Adjusted to 155 g/kg moisture.

‡ Measured on a scale of 1 to 3, 3 being most vigorous.

§ Stand counts were taken early, VE-V1, and late, V3-V5. Reported as number of plants out of 64 kernels planted

¶ Not significant at the 0.05 level

Table 4 - Means reported for hybrid x seed source.

Hybrid	Source	Yield	Vigor	Stand Count		Moisture	Lodging	
				Early	Late		Stalk	Root
		Mg ha^{-1}†	‡	§		g kg^{-1}	%	
B110/B122	Summer	13.19	2.17	58.03	57.33	219.6	0.063	0.041
	Winter	10.23	1.19	38.69	41.72	227.9	0.039	0.010
B110/LH295	Summer	12.93	2.53	58.58	57.81	197.5	0.022	0.079
	Winter	11.35	1.26	43.60	46.23	204.0	0.012	0.046
LH244/B122	Summer	12.32	2.19	59.36	57.25	216.8	0.025	0.008
	Winter	11.46	1.75	56.89	56.14	219.0	0.018	0.001
LH244/B125	Summer	13.21	2.58	59.64	59.14	209.4	0.040	0.006
	Winter	12.69	1.94	57.51	56.03	208.7	0.051	0.000
LH244/LH295	Summer	12.73	2.64	54.61	53.39	196.9	0.009	0.009
	Winter	12.70	2.17	57.83	56.72	199.5	0.021	0.038
LSD(0.05)		0.79	0.24	2.25	2.10	NS ¶	0.017	0.019

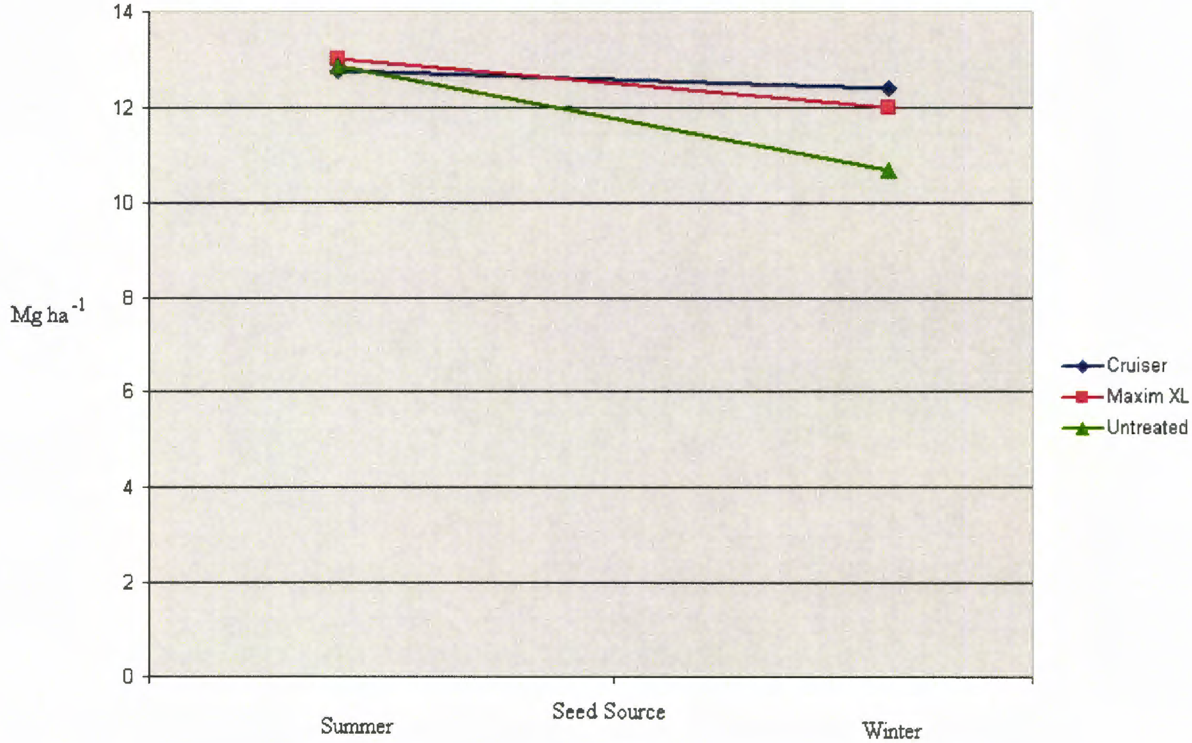
† Adjusted to 155 g/kg moisture.
‡ Measured on a scale of 1 to 3, 3 being most vigorous.
§ Stand counts were taken early, VE-V1, and late, V3-V5. Reported as number of plants out of 64 kernels planted
¶ Not significant at the 0.05 level

Table 5 - Means reported for seed treatment x seed source interaction.

Treatment	Source	Yield	Vigor	Stand Count		Moisture	Lodging	
				Early	Late		Stalk	Root
		Mg ha^{-1}†	‡	§		g kg^{-1}	%	
Untreated	Summer	12.85	2.37	58.30	56.33	207.2	0.028	0.032
	Winter	10.66	1.40	45.00	45.08	214.4	0.023	0.020
Maxim XL	Summer	13.02	2.48	57.20	56.62	207.9	0.033	0.035
	Winter	12.00	1.75	53.56	52.78	208.6	0.030	0.014
Cruiser	Summer	12.76	2.41	58.63	58.00	209.0	0.034	0.018
	Winter	12.40	1.84	54.15	56.23	212.5	0.032	0.023
LSD(0.05)		0.61	0.19	1.75	1.63	NS ¶	NS ¶	0.015

† Adjusted to 155 g/kg moisture.
‡ Measured on a scale of 1 to 3, 3 being most vigorous.
§ Stand counts were taken early, VE-V1, and late, V3-V5. Reported as number of plants out of 64 kernels planted
¶ Not significant at the 0.05 level

Graph 1 - The effect of seed treatments on yield of different sources of seed.



CHAPTER 4. GENERAL CONCLUSIONS

The objective of this study was to determine the effect of seed treatment on small plot evaluation in multiple location yield trials. The conclusions drawn from this study are important to corn breeders.

First, differences between seed sources are most likely differences in components of seed quality, chiefly seed vigor. Seed vigor is determined and affected by a multitude of factors, many of which could be genotype specific. It would appear that seed with high vigor has little problems emerging into healthy seedlings. It is when vigorous seed is not used that seed is vulnerable to attack by soil-borne pathogens. This results in less vigorous seedlings and a reduction in stands. This outcome is undesirable for corn breeders. Instead of selection based upon genotype performance, selection based upon seed components of quality could result, once again, an undesirable result for corn breeders.

Thus enters the role of seed treatments. If seed is guarded against these soil-borne pathogens by a seed treatment then the consequences of lowered seed vigor may be reduced in severity or eliminated all together. This was seen in this study. The seed with low seed vigor from winter nursery regained much of what was lost in stand, seedling vigor, and yield when the seed was treated with Maxim XL. Cruiser seemed to make little difference in this study. The only significant difference that was observed between Maxim XL treated seed and Maxim XL + Cruiser was in the late stand counts. This makes sense as many insect pests would feed upon seedlings in the time between when the early stand counts were taken and when the late stand counts were taken. This overall increase in stand did not result in increased yields.

It is not the conclusion of the authors that seed treatments are not a surrogate for good seed. The first objective of the breeder should be producing high quality seed for evaluation, with good seed vigor and high germination capacity. Differences in seed vigor across genotypes that are to be evaluated will occur, even if all seed originates from a single source. Treating seed, especially with a fungicide, does improve and restore most of what is lost in stands, vigor, and yield.

Seed treatments help to ensure that the genetic potential of several agronomic traits of interest are fully expressed. This is what accounts for the increase in data quality. Seed treatments do provide an increase in data quality, and therefore; their use should be employed by corn breeders.

APPENDIX - ADDITIONAL TABLES AND FIGURES

Table 6 - Results from the Analysis of Variance of measured traits with the hybrid B110/B122 removed from the analysis.

Source of Variation	Early Stand	Vigor	Late Stand	Root Lodging	Stalk Lodging	Moisture	Yield
Hybrid	*	*	*	*	*	*	*
Treatment	*	*	*	NS	NS	NS	*
Source	*	*	*	NS	NS	NS	*
Hybrid x Treatment	NS†	NS	NS	NS	NS	NS	NS
Hybrid x Source	*	*	*	*	NS	NS	NS
Treatment x Source	*	*	*	NS	NS	NS	NS
Hybrid x Treatment x Source	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.
† NS, nonsignificant at the 0.05 level.

Table 7 - Results from the Analysis of Variance of measured traits with the winter seed source removed.

Source of Variation	Early Stand	Vigor	Late Stand	Root Lodging	Stalk Lodging	Moisture	Yield
Hybrid	*	*	*	*	*	*	NS
Treatment	NS†	NS	*	NS	NS	NS	NS
Hybrid x Treatment	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.

† NS, nonsignificant at the 0.05 level.

Table 8 - Results from the Analysis of Variance of measured traits with summer seed removed.

Source of Variation	Early Stand	Vigor	Late Stand	Root Lodging	Stalk Lodging	Moisture	Yield
Hybrid	***	***	***	***	***	***	***
Treatment	***	**	***	NS	NS	NS	**
Hybrid x Treatment	***	NS†	***	NS	NS	NS	NS

* Significant at the 0.05 probability level.

† NS, nonsignificant at the 0.05 level.

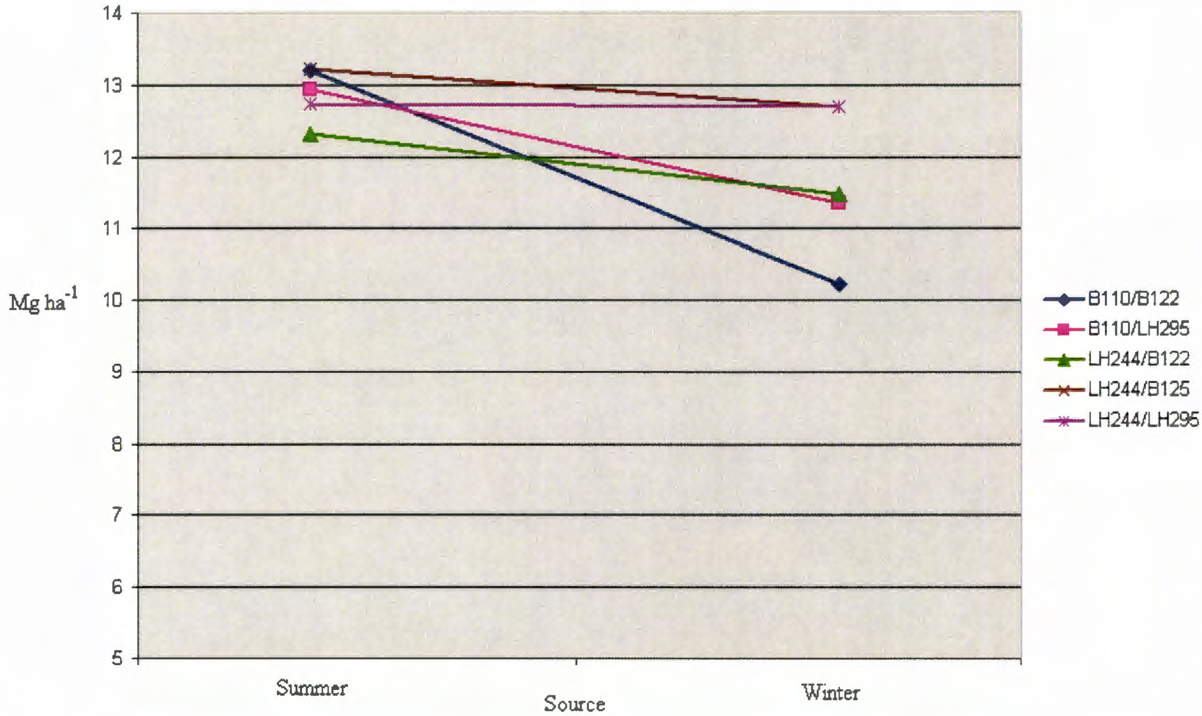
Table 9 - Results from the Analysis of Variance of measured traits with untreated seed removed.

Source of Variation	Early Stand	Vigor	Late Stand	Root Lodging	Stalk Lodging	Moisture	Yield
Hybrid	*	*	*	*	*	*	*
Treatment	NS†	NS	*	NS	NS	NS	*
Source	*	*	*	NS	NS	*	*
Hybrid x Treatment	NS	NS	*	*	NS	NS	NS
Hybrid x Source	*	*	*	*	*	NS	*
Treatment x Source	NS	NS	*	*	NS	NS	*
Hybrid x Treatment x Source	NS	NS	*	NS	NS	NS	NS

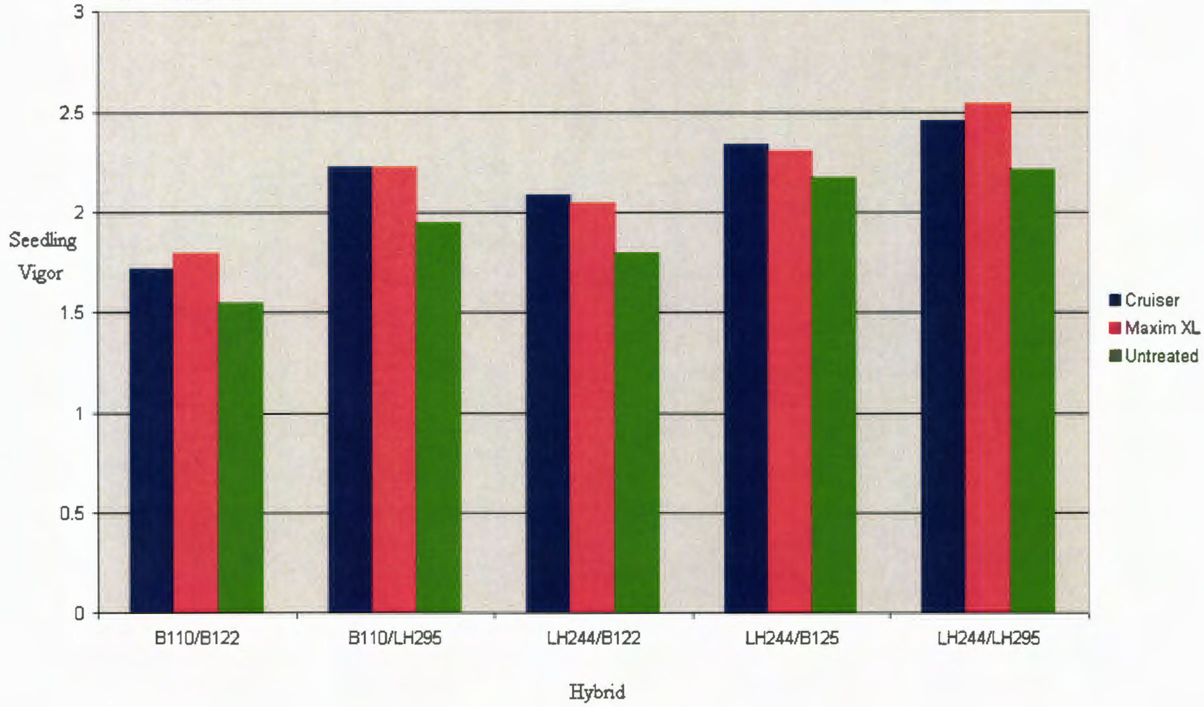
* Significant at the 0.05 probability level.

† NS, nonsignificant at the 0.05 level.

Graph 2 - The effect of source on yield of the 5 hybrids studied.



Graph 3 - The effect of seed treatment on seedling vigor of the 5 hybrids studied. Vigor was measured on a scale of 1 to 3, with 3 being the most vigorous.



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